Lab – 2

Mechanical characterization of soft materials

Objective

Subjecting filled rubber material to cyclic loading and quantifying energy dissipation in the material.

Introduction

Natural rubber has several industrial applications due to its large deformation and vibration absorption characteristics. It has the capability to release the absorbed energy (subsequently) in a different mode. Rubber in its natural form is quite compliant, therefore, often rigid particles, such as carbon black, clay etc., are reinforced into to improve its mechanical properties. In aerospace industries the filled rubber is used as vibration dampers. Filler rubber is also used in thermal insulation, O-rings, window and door seals, HVAC seals, gaskets, etc.

Uniaxial tensile test is common method to characterize mechanical behaviour of materials. In displacement control mode, the specimen is stretched at pre decided rate and the response of the material is recorded. A primary measure to document the deformation of material is stretch ratio (λ), which is defined as the ratio between the final length of the specimen to its initial length. Strain ($\in$) is another parameter for defining deformation. The (small) strain is defined as a ratio between the change in length over the initial length of the specimen. For the deformed specimen, illustrated in Fig. 1, $\lambda = \frac{(l+\Delta l)}{l}$ and $\in = \frac{\Delta l}{l}$.

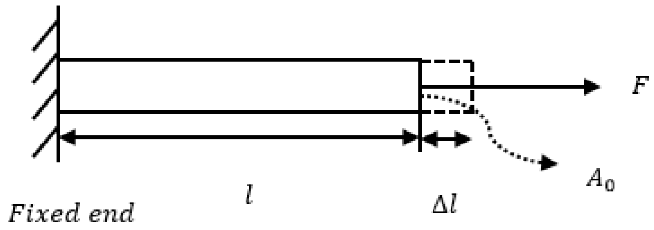
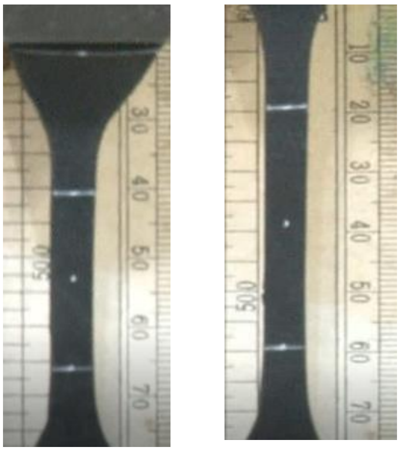


Fig. 1. Deformation in a tensile specimen, subjected to uniaxial loading

The large deformation is usually quantified by using the stretch ratio. Soft materials undergo large uniaxial deformation, which cause significant change in their cross-section area. Therefore, nominal and instantaneous stress are different in such materials. Nominal stress is defined as the force divided by the initial cross-section area in the undeformed configuration. Thus, if A_0 is initial cross-section area then,

$$Nominal\ stress, \sigma_n = \frac{F}{A_0}.$$



$l_0 = 25\ mm$ $\quad$ $l \sim 40\ mm$

Figure 2. Filled rubber subjected to uniaxial tension

The objectives of this lab is to observe and analyse non-linear mechanical behaviour of filled rubber and quantify Mullin's effect. Upon subjecting to uniaxial loading, the rubber material shows large deformation (See Fig. 2). Representative plot between nominal stress and the stretch is shown in Fig. 3.

When filled rubber is stretched and then unstretched to a zero-load condition, it does not follow original loading path. Also, the material does not attain zero deformation upon complete unloading. The residual deformation corresponding to zero-load is known as permanent set. Subsequently, if the specimen is stretched again, then it attains the prescribed deformation at lower load when compared to the case of first cycle. This (increasing) stress softening in subsequent cycles is known as Mullins Effect in filled rubber. The effect of loading, unloading and reloading on the stress-stretch behaviour of filled rubber is illustrated in Fig. 4.

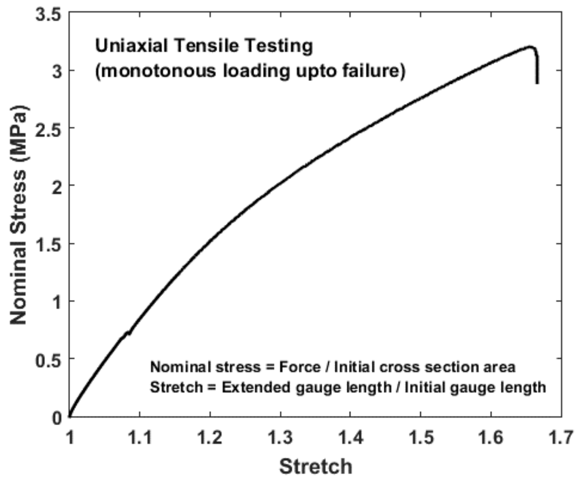


Figure 3. Uniaxial tensile testing for filled rubber (stress-stretch curve)

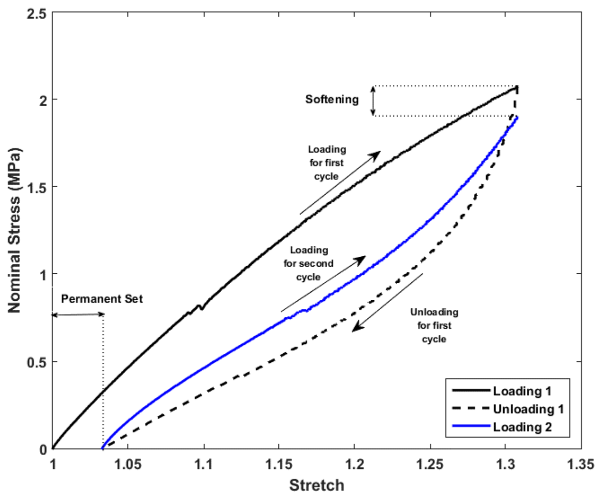


Figure 4. Stress-stretch curve obtained by loading, unloading and reloading rubber material.

Different loading and unloading paths indicate a loss in the energy, that has gone into stretching the material. The dissipative behaviour in rubber material is observed due to its viscoelastic nature. The dissipated energy in a loading-unloading cycle is quantified by the area enclosed within the loading and unloading curves.

Experimental setup

A Universal Testing Machine (UTM) is used to perform the experiments. The UTM used in this experiment is a 10 kN Tinius Olsen. The components of the UTM are illustrated in Fig. 5.

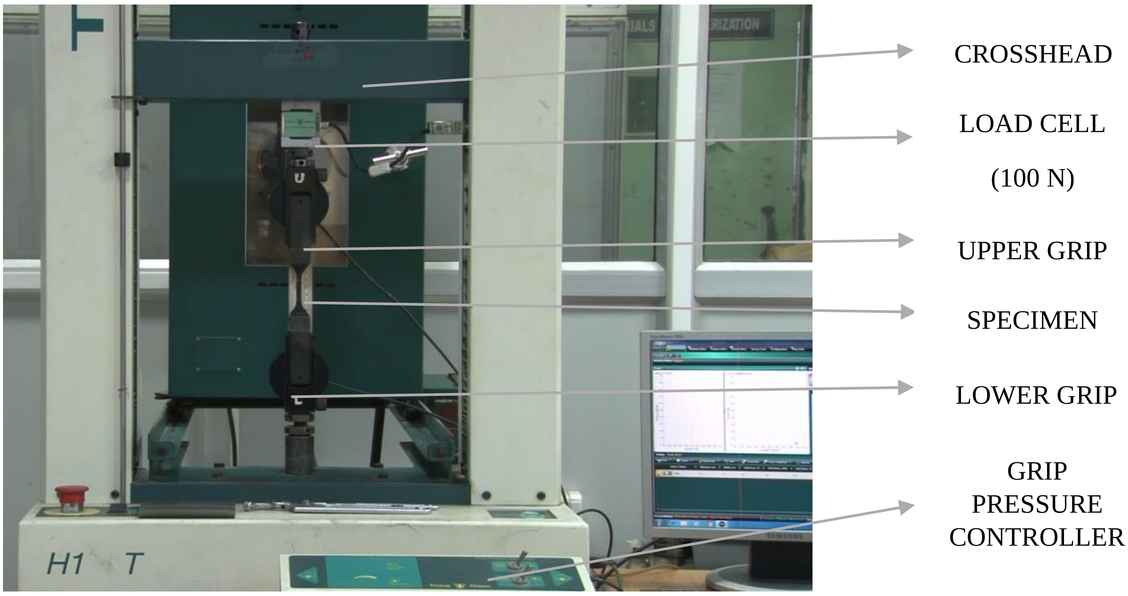


Figure 5. Tinius Olsen UTM with 10 kN load cell and pressurized grips

The crosshead is the part of the machine which moves at a prescribed displacement rate. Since this is a screw-driven machine, the movement of the crosshead is controlled by the rotation of the screws. The load cell is the component which measures the reaction force provided by the deformed specimen. Since filled rubber samples are quite compliant, therefore, a 100 N load cell is used. Grips of a UTM can be mechanical or pressure controlled. Since filled rubber is a soft material, it is important to provide equal tightening force in upper and lower grips. So, a pressurized grip set is used along with a grip pressure controller.

Two different experiments are conducted in this Lab.

(i) Monotonous loading: The specimen is stretched at a constant displacement rate This provides stress-stretch behaviour and failure stress and stretch values.

(ii) Cyclic tensile loading: The specimen is stretched to a predefined stretch value and then unstretched to zero load level. The loading unloading cycle is carried out 5 times.

Specimen configuration

A sheet of filled natural rubber of grade 70160 (obtained from TATA Rubber Corp, Ghaziabad, UP) of thickness $2.50\,mm$ is used to perform the experiments. The constituents of the vulcanized rubber sheet are, natural rubber, recycled and reclaim rubber, sulphur, and 5-10 PHR carbon black.

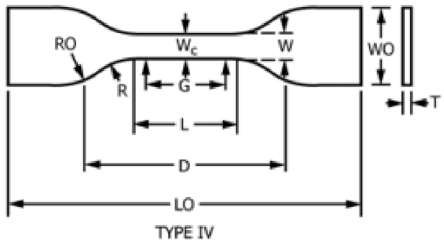


Figure 6. ASTM D638 type IV specimen (ref. ASTM D638-14)

Samples are cut out from the sheet as per ASTM D638 standards. A schematic diagram of the sample is shown in Fig. 6. The specimens are prepared with the width of narrow section, $W = 6mm$, length of narrow section, $L = 33mm$, distance between grips, $D = 65mm$ and gauge length, $G = 25mm$.

Experimental procedure

Following experimental procedure is followed to conduct the experiments.

(i) A 100 N load cell with pneumatic pressure-controlled grips are mounted on the machine.

(ii) The sample is loaded with the distance between grips 65 mm.

(iii) Specimen is subjected to pre-defined displacement rate under quasi-static loading condition, until the failure is observed in the material. The force vs. stretch data, recorded by the equipment, is analysed.

(iv) For subjecting the specimen to cyclic loading, a displacement/stretch, less than the one associated to failure, is defined. The sample is loaded to this prescribed displacement and then unloaded until zero-load is attained. The loading-unloading cycle is repeated 5 times.

Calculations and post-processing of data

In the Lab report following calculations and/or plots should be shown and analyzed.

(i) Plot the nominal stress vs. stretch data for monotonous loading in a single graph. Infer the failure stress and stretch values. Provide your observations.

(ii) Plot the nominal stress vs. stretch data for cyclic loading in a single graph. Provide your observations.

(iii) Plot the nominal stress vs. stretch data for both monotonous and cyclic loading in a single curve (with X axis limit of +0.1). Comment and compare the two curves.

(iv) Plot the crosshead displacement vs. time data for cyclic loading. Find out the permanent set values after each loading-unloading cycle. Plot the permanent set for the 5 cycles with respect to cycle number. Explain the trend of the curve in your own words.

(v) Calculate the energy dissipated in each of the 5 cycles. Plot their evolution. Explain the characteristic behaviour of energy dissipation with respect to loading-unloading cycle number. (Note that energy dissipated in one loading unloading cycle is the area under the unloading stress strain curve subtracted from the area under the loading stress strain curve. Strain can be assumed as change in length divided by the initial length)

$$Dissipated\ energy = \int_{loading} (\sigma . d \in) - \int_{unloading} (\sigma . d \in)$$

A lab report should contain:

(i) Objective of experiment
(ii) Introduction and theory of [a] Viscoelastic material and [b] Mullins effect
(iii) Experimental setup
(iv) Material and specimen description

(v) Experimental procedure
(vi) Calculations and graphs
(vii) Conclusion
(viii) Precautions and sources of error

The graphs should be properly labelled along with the units mentioned in the axes.